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Operational issues on Gas Turbine combustors for a Combined Cycle Power Plant

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ABSTRACT

Combined cycle gas turbine (CCGT) power plant is one of the cleanest and most efficient ways for fossil fuel power generation. A CCGT system uses the technologies of gas turbines and steam turbines to produce electricity more effectively than can be achieved using either of these technologies separately. Lean premixed flame is agreed to be the state-of-the-art technology for power plant gas turbines due to its great efficiency and especially low NOx emission. Despite of the high system efficiency and low harmful exhaust gases, there have been technical issues called "combustion instability" in the lean premixed gas turbine combustors, which are the feedback relationships between heat release oscillations and pressure wave perturbations. In this paper, the operational issues of the lean premixed combustor including the combustion instabilities and its basic mechanisms were explained.

Keywords: Combined cycle power plant; Gas turbine; Lean premixed combustor; Combustion instability

INTRODUCTION

Typical thermal power plants do not use all of their thermal energy for electricity generation. For the case of most plants, the considerable portion of energy could be lost as waste heat. This means that more energy input could be used to produce the same amount of meaningful energy. Combined cycle gas turbine power plant utilizes this waste energy as heat source in secondary turbine.

Figure 1 shows a typical example of combined cycle gas turbine (CCGT) power plant. A typical CCGT plant is composed of a gas turbine power cycle (Brayton cycle) and a steam turbine power cycle (Rankine cycle). The gas turbine is mostly powered by natural gas or gaseous fuel such as LPG, LNG, and generates electric power through expansion of hot gasses in a gas turbine. The Rankine(steam) cycle is provided with the still hot gaseous flow emitted from the gas turbine and produces both electricity and steam for the most efficient way to maximize the profits due to the sales of both steam and electricity and to minimize the operating costs [1-3].

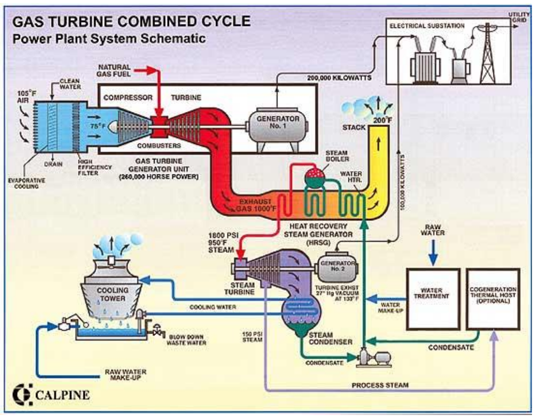

Fig. 1: Schematics for combined cycle gas turbine plant (courtesy of power-technology.com).

From the Korean statistical report on the electric power generation[2, 3], the production depends most greatly on the thermal power plant, followed by nuclear and CCGT. However, with the increase in power consumption and needs for cleaner power generation system, it is obvious that the portion of CCGT will get greater than that of the conventional thermal power generation system[2, 3]. Figure 2 shows a picture of Daegu power plant(an electrical capacity of 415M and an efficiency of over 61%) which is one of the biggest CCGT in Korea. The CCGT typically has 2-15 gas turbines as a power source dependent upon the amount of power generation. Figure 4 shows a picture of H-class gas turbine(Siemens) which is used in the Daegu power plant.

Fig. 2: Daegu combined cycle gas turbine plant.

Fig. 3: H-class gas turbine (courtesy of Siemens)

In this paper, some challenges and technical issues on the gas turbine combustor and the current development trends for CCGT are reviewed, and a novel combustion concept for low emission for the gas turbine.

Gas turbine combustors for CCGT:
Emission issues

All of the technologies applied for generating electricity have their related environmental issues. One of key critical emissions is nitrogen oxides(NOx). NOx is generally known as summation of Nitrogen dioxide (NO_2) and nitric oxide (NO). NOx plays an severe role in the formation of ozone and smog and has a great effect on the chemical reactions of other atmospheric species. Therefore, NOx can have huge effects on human health, atmospheric composition, acid deposition, irradiative forcing, and so on. Thermal power plants are one of the greatest sources in a lot of countries including Korea[4-6].

Lean premixed combustor:

Since the mid 1970's, NOx emissions from conventional combustion systems (in Fig. 4) have been decreasing from levels between 90 to 250 ppmv, parts per million by dry volume at 15 % oxygen, to less than 50 ppmv, using various water and steam injection techniques.

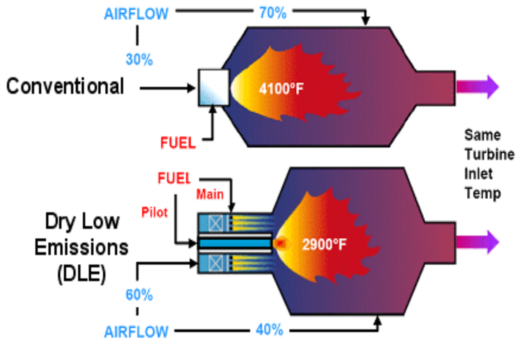

Fig. 4: H-class gas turbine (courtesy of Ramgen)

NOx emissions form in the primary zone of the combustion chamber. The highest gas temperature and subsequent NOx emissions occur at the stoichiometric condition, under which the flame temperature is almost highest fuel-air ratio. As shown in Fig. 4, the current gas turbines use the dry low emission combustor where the combustor is run under very lean fuel-air ratio in order to obtain the low flame temperature (= low NOx emissions)

Combustion dynamics:
Introduction to combustion instabilities:

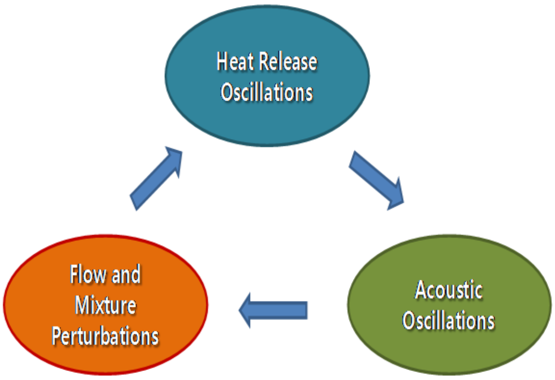

Fig. 5: Feedback relationship between heat release and combustor pressure oscillations

Despite of a high system efficiency and low NOx emission, the lean premixed combustor has a critical technical issue called combustion dynamics, feedback outcomes of heat release oscillations and pressure wave perturbations in the lean premixed combustor. Operating conditions of the lean premixed combustor is around lean blow out area(very low equivalence ratio). In these conditions, flames can easily show responses to even small amount of inlet flow fluctuations such as flow velocity and equivalence ratio oscillations, which results in the pressure oscillations. This unsteady heat release makes pressure wave fluctuations in the combustor as a result of the unsteady volumetric gas expansion. This pressure wave travels toward the mixing section and fuel nozzle, which makes the flow velocity and equivalence ratio fluctuation, and again these unsteady flow conditions increase the amplitude of heat release oscillation. That is why the combustion dynamics is called the feedback between the unsteady heat release and the pressure wave[4-9]. Figure 8 shows a schematic diagram of the feedback relationship between the heat release and the combustor pressure fluctuations to cause the combustion instability in the lean premixed gas turbine combustor.

In case that this instability is encouraged in the combustor over a certain period of time, large thermal stress and great amplitude of vibration would be produced, and they can damage major part of the combustor and the turbine, such as a combustor liner and fuel nozzle[7-9]. The cost for the repair and replacement of hot section components, much of which is directly attributable to the combustion instability problem, exceeds $1 billion annually and constitutes up to 70% of the non-fuel costs of F-class gas turbines.

Over the last decade, a lot of research groups in industrial, government, and academic communities over the world have taken their efforts to understand the severe problems concerned about combustion instability in low emissions gas turbine.

Flame transfer function:

In order to exactly predict information on frequency and phase delay that the instability occurs in the gas turbine, it is prerequisite to clearly understand the flame's dynamic response to external flow fluctuations. Commonly used way to quantify the flame dynamics is to obtain flame transfer function[7-9]. For a perfectly premixed flame(with no equivalence ratio fluctuation), the flame transfer function is defined as,

$$H_u(f \text{ or } \omega) = \frac{q'/q_m}{u'/u_m} \qquad (1)$$

where, q' and qm are fluctuation and mean values of heat release, and u' and um are fluctuation and mean values of flow velocity, respectively.

For measuring the flame transfer function, a flow modulation system would be used to force the inlet flow to be fluctuated. Detailed information on the flow modulation system and the flame transfer function, please refer to the previous studies[9].

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The flame transfer function can be determined by both calculations and measurements. Figures 6 and 7 show the mesh generation results for CFD(Computational Fluid Dynamics) and analysis results under the condition of 60m/s inlet mean velocity, respectively. As shown in the plot, the flow velocity contour in the combustor can be successively calculated using the CFD techniques.

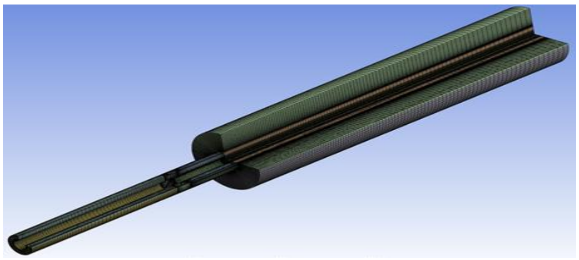

Fig. 6: Mesh generation results of the model combustor for CFD.

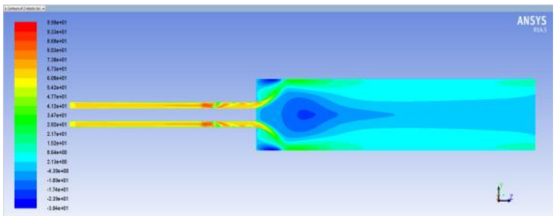

Fig. 7: Velocity contours in the combustor

Figure 8 compares the calculated flame transfer function results with the measured ones. Here, the ratio between the normalized velocity and heat release fluctuations is taken under the conditions of 10% velocity amplitude. From the comparisons, the calculations show the quite close results to the measurements especially for 100~200Hz modulation conditions.

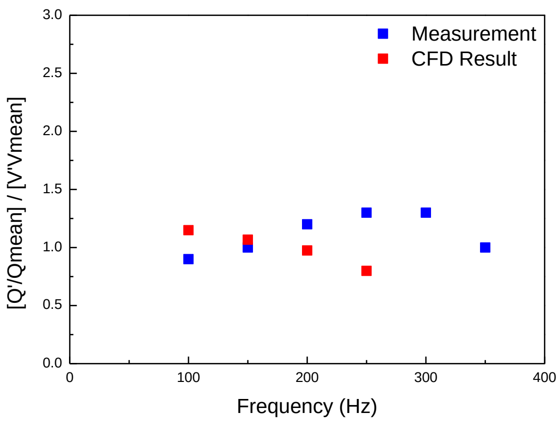

Fig. 8: Comparisons of the normalized heat release fluctuations between calculation and measurement.

Conclusions:

Combined cycle cogeneration power generation is the cleanest and the most efficient way for fossil fuel power generation. A CCGT system combines the technologies of gas turbines and steam turbines to produce electricity more efficiently than can be done using either of these technologies separately. Lean premixed combustion technology is considered to be the state-of-the-art system for stationary gas turbines for its great efficiency and especially low NOx emission. In spite of their advantages, the lean premixed combustor has a critical technical issue called combustion dynamics, feedback outcomes of heat release oscillations and pressure wave fluctuations in the lean premixed combustor. In this paper, the concept of the combustion dynamics and its fundamental mechanisms were explained, and as one of the method to predict and control the instability in the gas turbine combustor, flame transfer function could be effectively used to understand flame dynamics.

Acknowledgments

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